# C3 run plans

*$C^3$ session - Community Summer Study - Seattle*

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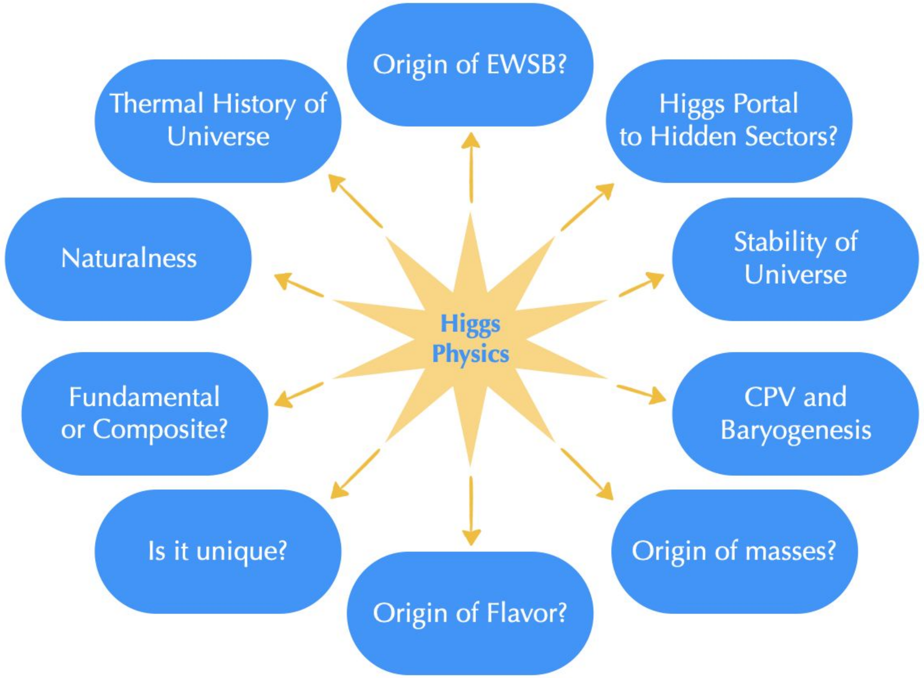
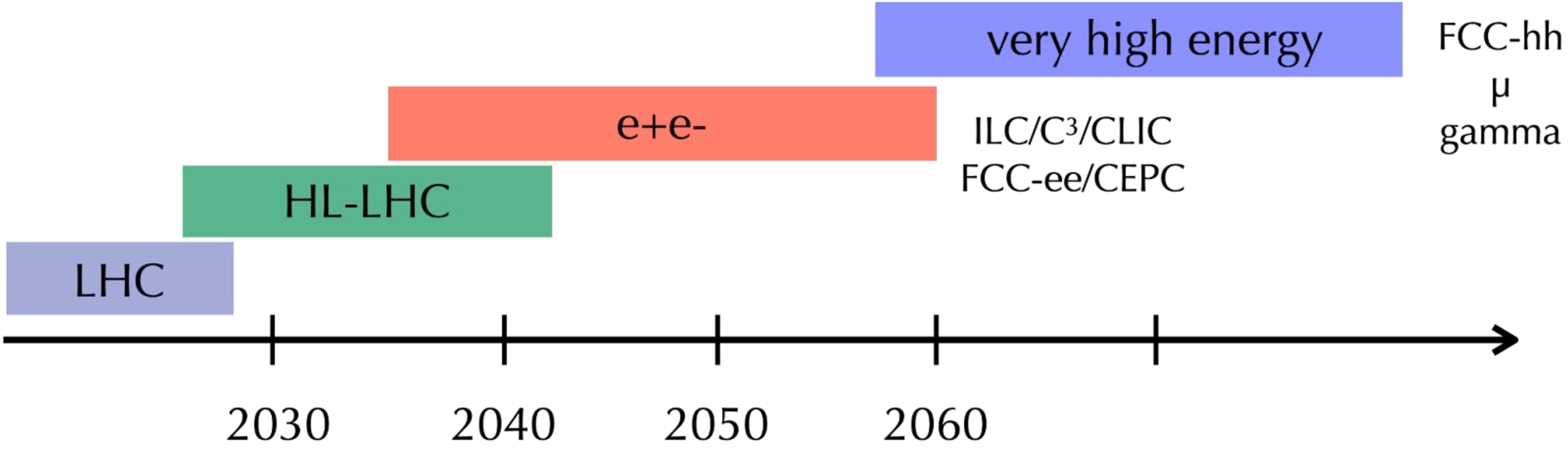
# Higgs as a driver to explore the unknown

## A roadmap

- The Higgs boson is our most recent advance in the understanding of the fundamental particles
- Colliders are essential to explore the properties of the Higgs boson
- Cool Copper Collider ($C^3$) : can provide a rapid route to precision Higgs physics with a compact footprint



# What’s Next for the Energy Frontier?




Wish list beyond HL-LHC:

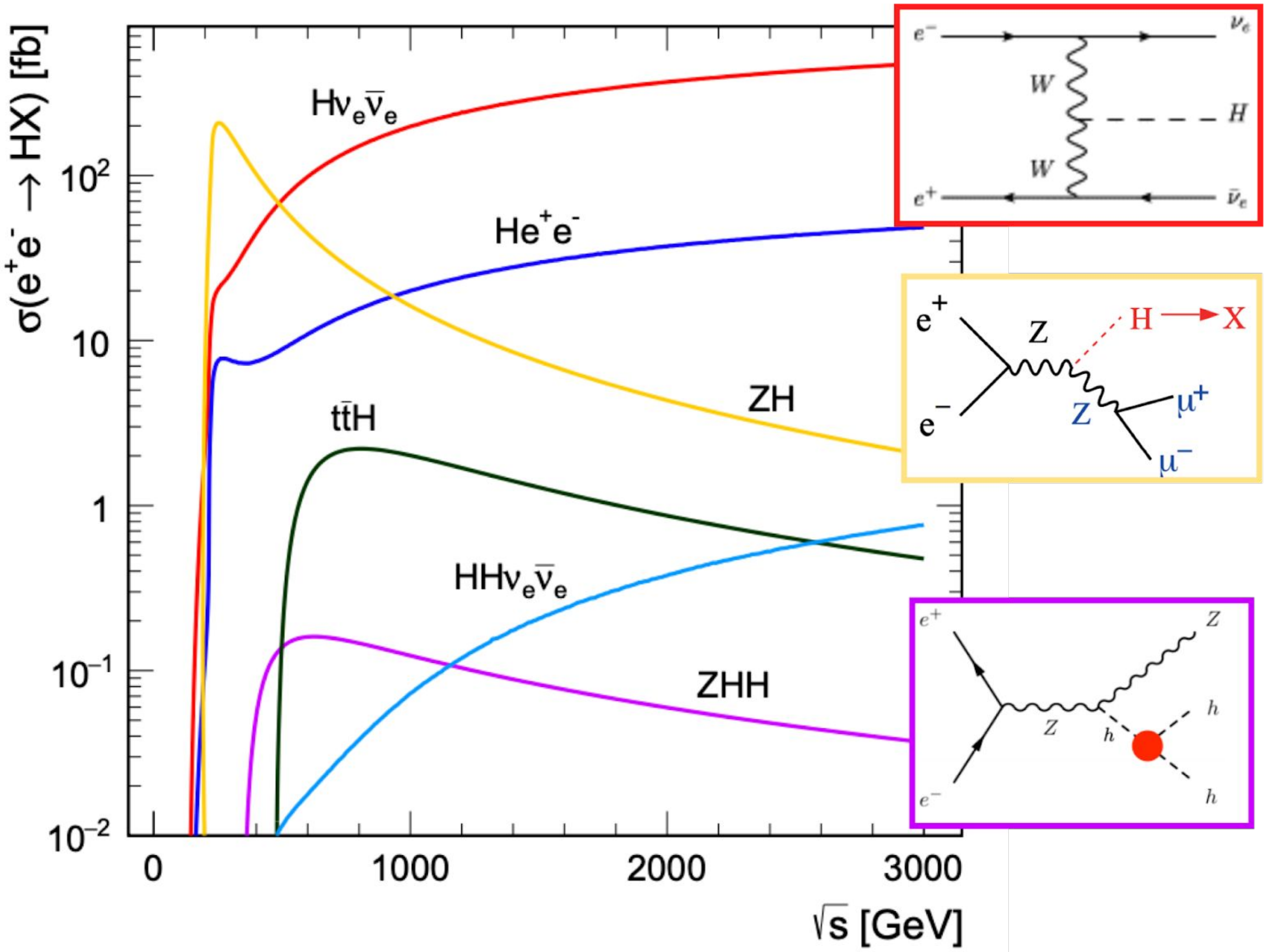
1. Establish Yukawa couplings to light flavor $\Rightarrow$ needs precision
2. Search for invisible/exotic decays and new Higgs $\Rightarrow$ precision & lumi
2. Establish self-coupling $\Rightarrow$ needs high energy

# Higgs Production at $e^+e^-$

ZH is dominant at **250 GeV**

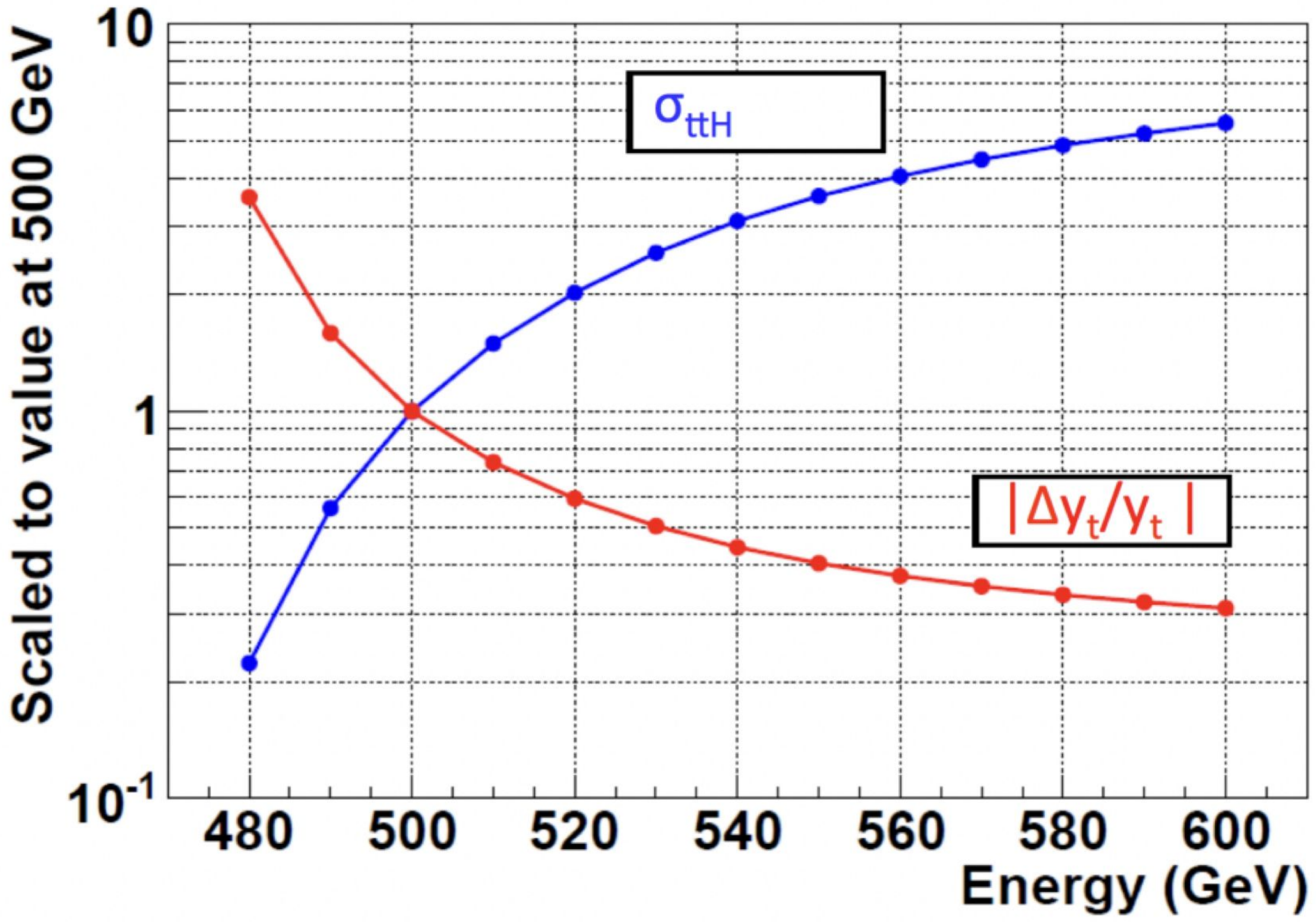
Above **500 GeV**

- Hvv dominates
- ttH opens up
- HH production accessible with ZHH



# Higgs-top coupling

From 500 to 550 GeV a factor two gain in precision on the Higgs-top coupling



# Why 550 GeV?

We propose **250 GeV** with a relatively inexpensive upgrade to **550 GeV**

- An **orthogonal dataset** at 550 GeV to cross-check a deviation from the SM predictions observed at 250 GeV
- From 500 to 550 GeV a factor 2 improvement to the **top-Yukawa** coupling
- O(20%) precision on the Higgs **self-coupling** would allow to exclude/demonstrate at $5\sigma$ models of electroweak baryogenesis

| Collider<br>Luminosity<br>Polarization | HL-LHC<br>3 $ab^{-1}$ in 10 yrs<br>- | $C^3$ /ILC 250 GeV<br>2 $ab^{-1}$ in 10 yrs<br>$\mathcal{P}_{e^+} = 30\%$ (0%) | $C^3$ /ILC 500 GeV<br>+ 4 $ab^{-1}$ in 10 yrs<br>$\mathcal{P}_{e^+} = 30\%$ (0%) |
|---|---|---|---|
| $g_{HZZ}$ (%) | 3.2 | 0.38 (0.40) | 0.20 (0.21) |
| $g_{HWW}$ (%) | 2.9 | 0.38 (0.40) | 0.20 (0.20) |
| $g_{Hbb}$ (%) | 4.9 | 0.80 (0.85) | 0.43 (0.44) |
| $g_{Hcc}$ (%) | - | 1.8 (1.8) | 1.1 (1.1) |
| $g_{Hgg}$ (%) | 2.3 | 1.6 (1.7) | 0.92 (0.93) |
| $g_{H\tau\tau}$ (%) | 3.1 | 0.95 (1.0) | 0.64 (0.65) |
| $g_{H\mu\mu}$ (%) | 3.1 | 4.0 (4.0) | 3.8 (3.8) |
| $g_{H\gamma\gamma}$ (%) | 3.3 | 1.1 (1.1) | 0.97 (0.97) |
| $g_{HZ\gamma}$ (%) | 11. | 8.9 (8.9) | 6.5 (6.8) |
| $g_{Htt}$ (%) | 3.5 | – | 3.0 (3.0)* |
| $g_{HHH}$ (%) | 50 | 49 (49) | 22 (22) |
| $\Gamma_H$ (%) | 5 | 1.3 (1.4) | 0.70 (0.70) |

# One note on polarization

## arXiv:1708.08912, arXiv:1801.02840

- There are extensive comparisons between the FCC-ee plan and the C$^3$/ILC runs that show they are rather compatible to study the Higgs Boson
- When analyzing Higgs couplings with SMEFT, **2 ab$^{-1}$ of polarized running is essentially equivalent to 5 ab$^{-1}$ of unpolarized running.**
- Electron polarization is essential for this
- There is almost no difference in the expectation with and without positron polarization.
  - more cross-checks of systematic errors.
  - relevant at high energy (> TeV) where the most important cross sections are initiated from $e^{-L}e^{+R}$

| | 2/ab-250 | +4/ab-500 | 5/ab-250 | + 1.5/ab-350 |
|---|---|---|---|---|
| coupling | pol. | pol. | unpol. | unpol |
| $HZZ$ | 0.50 | 0.35 | 0.41 | 0.34 |
| $HWW$ | 0.50 | 0.35 | 0.42 | 0.35 |
| $Hbb$ | 0.99 | 0.59 | 0.72 | 0.62 |
| $H\tau\tau$ | 1.1 | 0.75 | 0.81 | 0.71 |
| $Hgg$ | 1.6 | 0.96 | 1.1 | 0.96 |
| $Hcc$ | 1.8 | 1.2 | 1.2 | 1.1 |
| $H\gamma\gamma$ | 1.1 | 1.0 | 1.0 | 1.0 |
| $H\gamma Z$ | 9.1 | 6.6 | 9.5 | 8.1 |
| $H\mu\mu$ | 4.0 | 3.8 | 3.8 | 3.7 |
| $Htt$ | - | 6.3 | - | - |
| $HHH$ | - | 27 | - | - |
| $\Gamma_{tot}$ | 2.3 | 1.6 | 1.6 | 1.4 |
| $\Gamma_{inv}$ | 0.36 | 0.32 | 0.34 | 0.30 |
| $\Gamma_{other}$ | 1.6 | 1.2 | 1.1 | 0.94 |

# Strategy for $C^3$

Run plans:

- Start at 70 MeV/m for $C^3$-250
  - 2/ab in 10 years operations
  - Polarized $e^-$ (80%)
- Upgrade with more RF power at 120 MeV/m for $C^3$-550
  - Same footprint as $C^3$-250
  - 4/ab in 10 years operations
  - Add polarized $e^+$ at this stage
- If there is community interest in the Z run :
  - $C^3$ can run at the Z pole at $4 * 10^{33}/cm^2s$ and deliver ~$10^9$ Z in 2 years (**Giga Z** program)

# Table of Parameters

| Collider | CLIC | ILC | $C^3$ | $C^3$ |
|---|---|---|---|---|
| CM Energy [GeV] | 380 | 250 (500) | 250 | 550 |
| Luminosity [x$10^{34}$] | 1.5 | 1.35 | 1.3 | 2.4 |
| Loaded Gradient [MeV/m] | 72 | 31.5 | 70 | 120 |
| Geometry Gradient [MeV/m] | 57 | 21 | 63 | 108 |
| Length [km] | 11.4 | 20.5 (31) | 8 | 8 |
| Num. Bunches per Train | 352 | 1312 | 133 | 75 |
| Train Rep. Rate [Hz] | 50 | 5 | 120 | 120 |
| Bunch Spacing [ns] | 0.5 | 369 | 5.26 | 3.5 |
| Bunch Charge [nC] | 0.83 | 3.2 | 1 | 1 |
| Crossing Angle [rad] | 0.0165 | 0.014 | 0.014 | 0.014 |
| Site Power [MW] | 168 | 125 | $\sim$150 | $\sim$175 |
| Design Maturity | CDR | TDR | pre-CDR | pre-CDR |

# Luminosity Upgrades

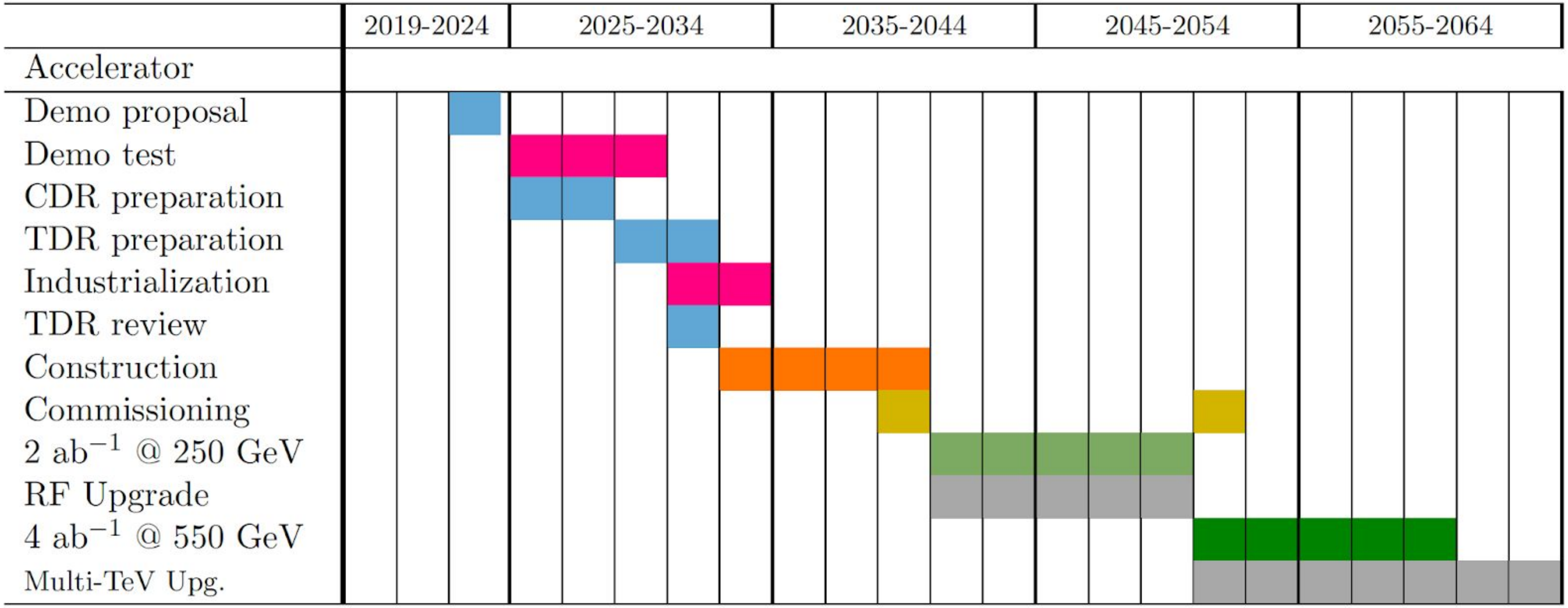
## Energy vs Luminosity: community feedback needed in developing the most appealing run plan

- **Beam power can be increased for additional luminosity**
  - To maintain overall site efficiency we have high beam loading constant ~50%
- **Multiple pathways exist to 2-4x Luminosity upgrades**
  - *e.g.* bunch format
- $C^3$ has a relatively low current for 250 GeV CoM (0.19 A)
  - Could we push to match CLIC at 1.66 A? (8.5X increase?)
  - **Requires increased focus on damping detuning & serious investigation of beam dynamics**
    - **great topic for $C^3$ Demonstration R&D**

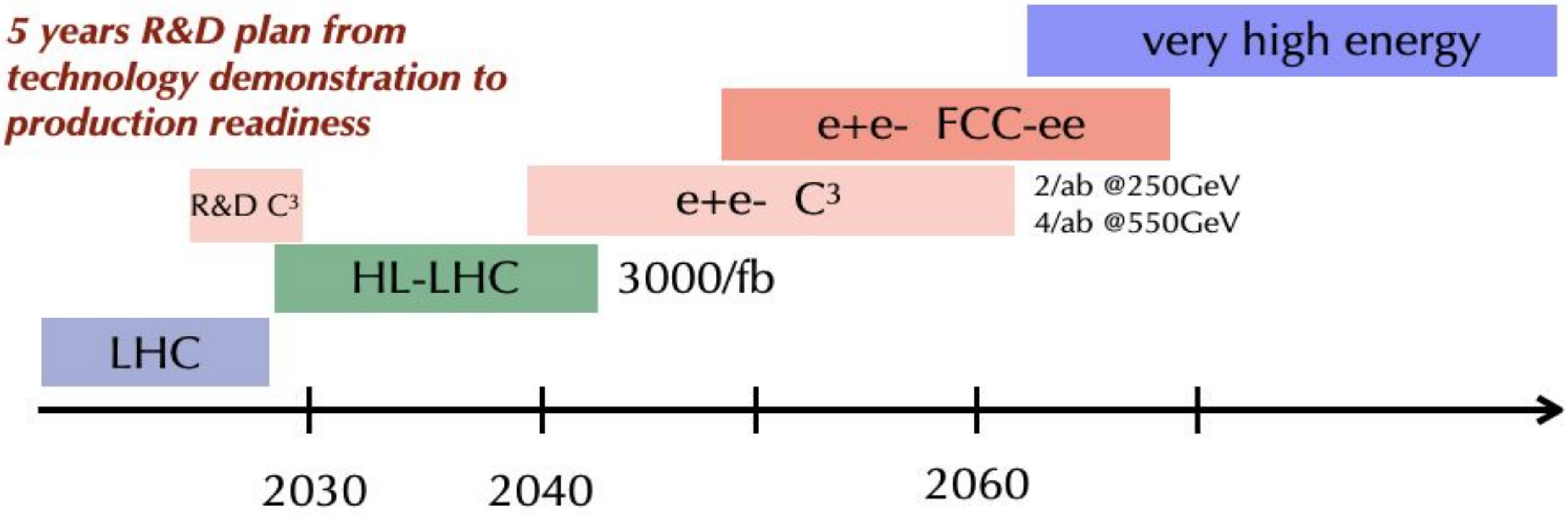
| Parameter | Units | Baseline | High-Lumi |
|---|---|---|---|
| Energy CoM | GeV | 250 | 250 |
| Gradient | MeV/m | 70 | 70 |
| Beam Current | A | 0.2 | 1.6 |
| Beam Power | MW | 2 | 16 |
| Luminosity | $x10^{34}$ | 1.3 | 10.4 |
| Beam Loading | | 45% | 87% |
| RF Power | MW/m | 30 | 125 |
| Site Power | MW | ~150 | ~180 |

# Technical Timeline for 250/550 GeV CoM

Technically limited timeline following community engagement through the full Snowmass process to define the parameters of the $C^3$ proposal



# Conclusions




- $C^3$ can provide a rapid route to precision Higgs physics with a compact footprint
  - Possibly, a US-hosted facility
- Depending on community interests we could prioritize differently Giga-Z, luminosity vs. energy upgrade
  - extension up to 2 (3) TeV possible with 14 (21.5) km tunnel and 155 MeV/m gradient

# Get in touch with us!

Info on how to register to mailing list: https://indico.slac.stanford.edu/event/7155/

Next workshop at SLAC, October 13-14 2022.

Stay tuned!

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## Strategy for Understanding the Higgs Physics: The Cool Copper Collider


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## $C^3$ Demonstration Research and Development Plan


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## $C^3$ : A "Cool" Route to the Higgs Boson and Beyond


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SLAC

# Backup

# Beam Format and Detector Design Requirements

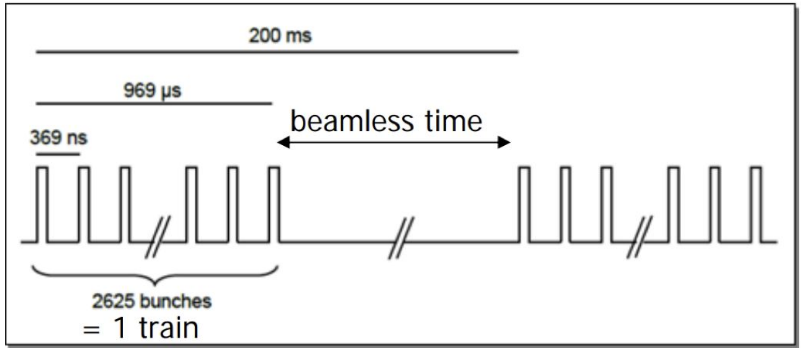
ILC timing structure: Fraction of a percent duty cycle

- **Power pulsing possible**, significantly reduce heat load
  - Factor of 50-100 power saving for FE analog power
- Tracking detectors **don't need active cooling**
  - Significantly reduction for the material budget
- **Triggerless readout** is the baseline

| Collider | ILC | CCC |
|---|---|---|
| $\sigma_z$ | 300 $\mu$m | 100 $\mu$m |
| $\beta_x$ | 8.0 mm | 13 mm |
| $\beta_y$ | 0.41 mm | 0.1 mm |
| $\epsilon_x$ | 500 nm/rad | 900 nm/rad |
| $\epsilon_y$ | 35 nm/rad | 20 nm/rad |
| N bunches | 1312 | 133 |
| Repetition rate | 5 Hz | 120 Hz |
| Crossing angle | 0.014 | 0.020 |
| Crab angle | 0.014/2 | 0.020/2 |

***$C^3$ time structure is compatible with SiD-like detector overall design and ongoing optimizations***

**ILC timing structure**




1 ms long bunch trains at 5 Hz
2820 bunches per train
308ns spacing

**$C^3$ timing structure**